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The Aerovox Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 12, NO. 7 JULY, 1940
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50c per year in U.S.A.
60c per year in Canada

Measuring Distortion in Audio-Frequency Amplifiers

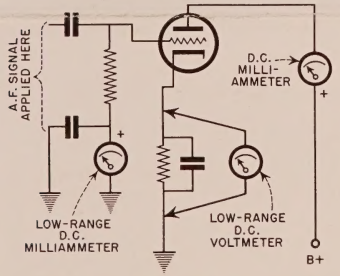
By the Engineering Department, Aerovox Corporation

THE simplest qualitative test for distortion in a Class A audio-frequency amplifier stage may be made, as shown in Figure 1, by applying a signal voltage of proper level to the input and inspecting the circuit for one or all of the following abnormal conditions:

(a) Presence of d.c. grid current,

(b) Fluctuation of the d.c. plate current,

(c) Fluctuation of the d.c. cathode voltage, if the circuit employs cathode resistor bias.



—SIMPLE AMPLIFIER STAGE WITH METERS FOR DETECTING DISTORTION—

Fig. 1

Each of these indications generally occurs in a positive direction, and each will disappear upon removal of the signal. It must be borne in mind, however, that this method is purely rudimentary in nature and serves only to detect the presence of distortion. One or two of the indications may be absent, depending upon the main cause of the trouble.

The three simple indications are well known and frequently used by servicemen and P.A. testers who have no equipment suitable for making quantitative distortion measurements, but must, in the course of routine testing, localize distortion without reference to the actual percent harmonic energy present.

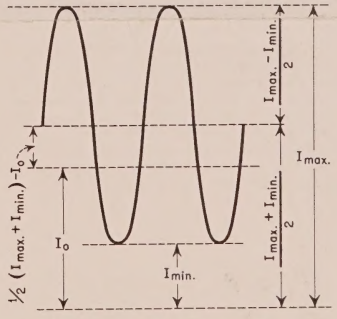


Fig. 2

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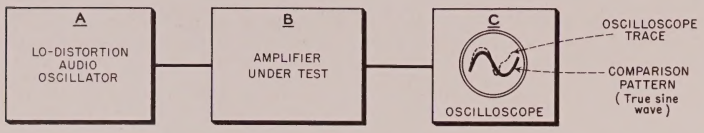

Fig. 3

The cathode circuit effects noted above are due to fluctuations in the voltage drop across the cathode resistor, occasioned by variations in the d.c. component of plate current. The current indicated by the plate-circuit milliammeter is the average value of the fluctuating "signal" plate current, is identical with the d.c. component, and is the current that produces the cathode resistor drop. These facts may be better comprehended when it is remembered that the fluctuating signal plate current (Figure 2) is an alternating current, corresponding to the signal, superimposed upon a direct current. It will be evident from the fundamental relations of this combination that the average value of plate current, as indicated by the plate-circuit milliammeter, will be constant in the company of the alternating component under distortionless operating conditions.

Figure 2 is a graphical representation of signal plate current. $I_{max.}$ is the maximum value reached by the fluctuating plate current; I_o, the zero-signal value; $I_{min.}$ the minimum value. From these values, it may be shown that the percent second-harmonic content (often the most troublesome distortion factor) is equal to:

$$\frac{\frac{1}{2}\left(I_{max.} + I_{min.}\right) - I_o}{I_{max.} - I_{min.}} \times 100$$

Quantitative methods of checking distortion are *harmonic analyses*, and are concerned with measurement of the actual amount of energy present in each separate harmonic of the signal frequency (or in the total harmonic content) and establishment of percentages with respect to the fundamental frequency. The most representative methods employed in wave analysis and the apparatus necessary thereto will be described presently.

OSCILLOSCOPIC METHOD

The cathode ray oscilloscope is notably useful in the observation of wave shapes. When the horizontal plates of the ray tube are energized by a saw-tooth wave sweep-oscillator-amplifier circuit to furnish the linear time base, and a signal voltage which it is desired to observe is applied to the vertical plates through a substantially flat-response amplifier, the cathode ray trace will be an exact reproduction of the wave form of the applied signal voltage.

An audio-frequency amplifier may be checked for distortion with the oscilloscope in the manner illustrated in Figure 3. *A* is an audio oscillator possessing an output voltage wave form of known purity, *B* is the amplifier under test, and *C* is an oscilloscope having horizontal and vertical amplifiers with substantially flat frequency responses. The units are connected in the order shown.

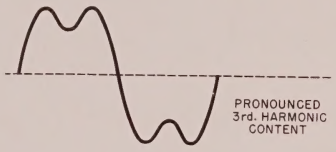

Fig. 4

It is the purpose of the oscillator to supply a signal of as pure wave form as practicable to the amplifier, and that of the oscilloscope to reproduce the wave shape of the signal after it has passed through the amplifier. In order that as little distortion as possible be introduced by the instruments themselves, the oscillator used for such a test must be of exceptionally high quality and the amplifiers in the oscilloscope must possess an excellent frequency characteristic. Likewise, the oscilloscope sweep circuit must be uncompromisingly linear in its characteristic.

If the amplifier had no distortion at all, the signal it delivered to the oscilloscope would be an exact reproduction of the input signal wave form. This is never encountered in practice, however, the most efficient amplifier arrangement being beset with the distortion characteristics of its tubes and other components.

For observations, a perfect sine wave (or, better still, a tracing of a single cycle from the test oscillator) might be inscribed on the transparent viewing screen of the oscilloscope, and signals from the amplifier matched to this pattern to discover variations from the original shape due to amplifier distortion. In making such a test, it would of course be necessary to adjust both oscilloscope amplifier gain controls in such manner that the maximum amplitude and width of the signal trace co-incided with those dimensions of the inscribed pattern.

With the low percentages encountered with most well-designed amplifying equipment, it will be difficult to estimate the percentage of harmonic content from the reproduced wave shape, in the oscilloscopic method, unless the operator makes use of the transparent screens furnished by some oscilloscope manufacturers for the purpose. These screens carry printed patterns of single cycles corresponding to the shapes obtained (variations from true sinusoidal) with various low percentages of distortion. Severe cases would result in images similar to Figure 4 which is an exaggerated representation of pronounced third-harmonic content.

FREQUENCY BRIDGES

Certain bridge circuits, notably the Wien bridge (see Figure 5) can be used for the identification of frequencies in the audio-frequency spectrum. If an alternating voltage is delivered to the bridge circuit, the latter may be adjusted for a null at that particular signal frequency. The null point would not hold for the same voltage of another frequency. Thus, the adjustable element of the bridge might be calibrated to read directly in cycles per second.

The Wien bridge in its most useful form for this purpose would have its constants so chosen that the ratio arm, R_2 is twice the ohmic value of R_1, the condensers C_1 and C_2 are equal in capacitance, and the two simultaneously adjustable resistance legs, R_3 and R_4 are at all positions equal. Under these conditions, the frequency

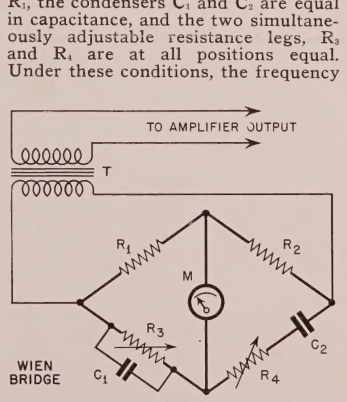

Fig. 5

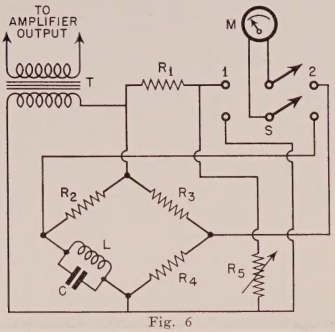

Fig. 6

of the impressed voltage at null would be equal to:

$$\frac{1}{2\pi RC}$$

Where:

Frequency is in cycles per second,
R is the resistance of R_3 or R_4 in ohms,
C is the capacitance of C_1 or C_2 in farads.

Since the bridge may be balanced for only one frequency at a time, it would appear that any residual voltage indicated by the vacuum-tube voltmeter, M at null would be due to some other frequency or frequencies (such as harmonics of the fundamental). And this harmonic voltage would be due to the total of harmonic voltages present. As such, the bridge might be connected, as shown in Figure 5, to the output circuit of an audio-frequency amplifier which is passing a signal from a high-quality audio oscillator.

While the device might be used as shown as such a harmonic totalizer, the percentage total harmonic content with respect to the readings of the meter before and after null would not be reliable, nor would its error be uniform for all frequencies. These facts are due to the peculiar nature of the bridge to attenuate various harmonics unequally.

Another popular type of bridge harmonic totalizer (due to UTC) is shown in Figure 6. Here, three legs of the bridge, R_2, R_3, and R_4, contain pure resistance, while the fourth leg contains the shielded parallel resonant circuit, LC which is resonant at the test frequency. The transformer, T, like the one shown in the bridge previously described, must have an excellent frequency characteristic.

At resonant frequency of LC, the inductive reactance of the tuned circuit equals the capacitive reactance, the former is cancelled by the latter, and the bridge balances as if all four legs were pure resistance. Any voltage applied by the circuit to the vacuum-tube voltmeter is then due to harmonics of the test frequency (and it is assumed that these harmonics have been delivered to the bridge by the amplifier under measurement).

In operation, the double-pole, double-throw switch, S is thrown to position 2 and the bridge balanced with the assistance of the vacuum-tube voltmeter, M as a null indicator. The reading at null (due to harmonics) is recorded. The switch is then thrown to position 1 and R_5 is adjusted until the meter gives the same reading (as before at null). The following calculation may be performed to determine the percent of total harmonics from this operation:

$$\%\,H = \frac{R_5}{R_4 + R_5} \times 100$$

or:

A dial indicator attached to the potentiometer R_5 may be calibrated directly in these percentages.

FILTER-METER

A very efficient method of measuring total harmonic content in the signal delivered by an audio-frequency amplifier makes use of the arrangement employed in the distortion and noise meters found in broadcast stations. (See Figure 7).

In this arrangement, the signal from a high-quality sine-wave audio test oscillator is fed into the amplifier under test. The amplifier output is connected to a high-pass filter which removes the test frequency but leaves all of its harmonics.

The actual voltage due to the harmonics is then measured by means of an attenuator and vacuum-tube output voltmeter. This measurement is one of total harmonic distortion, but it is entirely possible to arrange additional flat-response amplification with various high-pass filters to remove the various harmonics singly along with the fundamental.

WAVE ANALYZER

The wave analyzer, a highly-developed and refined form of heterodyne vacuum-tube voltmeter, provides the most advanced, accurate, and complete means of measuring amplifier distortion by determining the various harmonic voltage magnitudes. The instrument is tunable to the fundamental and any of a series of its harmonics separately, so that wave forms of considerable complexity may be investigated. At the same time, measurements of hum and noise amplitude are made available. In effect it is a highly selective electronic voltmeter.

The representative wave analyzer (General Radio) receives the signal to be inspected through an input channel embracing an input multiplier, amplifier, and pad (see the functional block diagram of Figure 8). The frequencies accepted by the input channel lie in the range 20 to 16,000 cycles per second—the entire common audio-frequency spectrum. A local heterodyne oscillator stage supplies heterodyning voltage of such frequency variation that throughout the signal input range, an intermediate frequency of 50 kc. may be produced. The dial controlling this oscillator is graduated

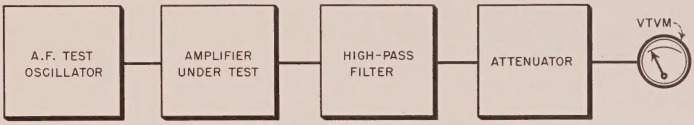

Fig. 7

in the frequencies admitted by the input channel.

The fixed-frequency 50 kc. i.f. channel is extremely sharp, containing three quartz crystals and is preceded by a balanced modulator, the output of which contains the upper and lower sidebands obtained from the heterodyning process. The carrier is suppressed. The superselective i.f. channel is followed by a 50 kc. amplifier and the indicating instrument.

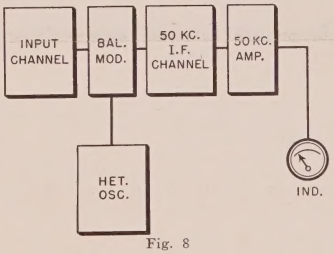

Fig. 8

In operation, the wave analyzer is tuned to the fundamental test frequency and then to the successive harmonics to an extent determined by the amount of frequency tuning range between the fundamental and the 16 kc. limit of the dial. The harmonic amplitudes are indicated directly by the meter.

Type 3GL (three-section) 8-8-8 450-volt unit and a GL 4 mfd. 450-volt unit. Note clean-cut can and handy inverted screw mounting, with colored flexible leads.

BELOW, the tiny GLS (8 mfd. 450-volt) unit alongside a familiar packaged candy for size comparison.

Inverted Screw - Mounting

ELECTROLYTICS

● Good old standbys—that's truly what these Type GL and the smaller GLS electrolytics mean to the experienced radio worker. With one, two and even three sections housed in a sturdy aluminum can; with the handy inverted screw mounting; with independent (two leads for each section) polarity-indicating 8-inch leads; with a conservatively rated voltage and full capacity and long life—what more could you ask for?

Note the exceptionally fine choice of working voltages, capacities, combinations, in the accompanying listings.

In the GLS type, extreme compactness is attained by the use of special etched foil. Note the 8 mfd. 450 volt GLS alongside a well-known candy package for size comparison.

Ask Your Jobber for Them...

● He'll gladly show you the GL and GLS Aerovox electrolytics. Use them in your very next job. You'll like their fine performance and exceptionally long life. Ask for latest Aerovox catalog—or write direct.

COMPACT GL ELECTROLYTICS

800v Surge—600v D.C.W.
Type GL600—Single Section

Cap. Mfds.	Dia.-High	List Price	Net Price
4	1⅜ x 4¼	$1.85	**$1.11**
8	1⅜ x 4½	2.60	**1.56**

600v Surge—475v D.C.W.
Type GL475—Single Section

4	1⅜ x 3	$1.25	**$0.75**
8	1⅜ x 4	1.50	**.90**
12	1⅜ x 4	2.05	**1.23**
16	1⅜ x 4½	2.30	**1.38**

Type 2GL475—Double Section

8-8	1⅜ x 4	$2.40	**$1.44**

525v Surge—450v D.C.W.
Type GL450—Single Section

4	1⅜ x 3	$0.85	**$0.51**
8	1⅜ x 4	1.05	**.63**
10	1⅜ x 4	1.25	**.75**
12	1⅜ x 4	1.40	**.84**
16	1⅜ x 4	1.55	**.93**
20	1⅜ x 4	1.75	**1.05**
40	1⅜ x 4	3.05	**1.83**
80	1⅜ x 4	4.25	**2.55**

Type 2GL450—Double Section

Cap. Mfds.	Dia.-High	List Price	Net Price
4-4	1⅜ x 4	$1.30	**$0.78**
4-8	1⅜ x 4	1.45	**.87**
8-8	1⅜ x 4	1.60	**.96**
8-16	1⅜ x 4	2.00	**1.20**
10-10	1⅜ x 4	1.95	**1.17**
16-16	1½ x 4	2.30	**1.38**
20-20	1½ x 4	2.75	**1.65**

Type 3GL450—Triple Section

4-4-4	1⅜ x 3	$1.90	**$1.14**
8-8-8	1⅜ x 4½	2.40	**1.44**
10-10-10	1½ x 4	2.65	**1.59**

300v Surge—250v D.C.W.
Type 3GL250—Triple Section

8-8-8	1⅜ x 3	$2.10	**$1.26**
8-8-16	1⅜ x 3	2.35	**1.41**
8-16-16	1⅜ x 4	2.60	**1.56**

Type GL 45025
450 x 25v. D.C. Work.

10-10 x 450 +20x25	1⅜ x 3	2.65	**1.59**

ULTRA-COMPACT GLS ELECTROLYTICS

525v Surge—450v D.C.W.
Type GLS450—Single Sec.

Cap. Mfds.		Dia.-High	List Price	Net Price
4	1	x 2- 3/16	$0.85	**$0.51**
8	1	x 2-11/16	1.05	**.63**
12	1	x 3- 3/16	1.40	**.84**
16	1	x 3- 1/4	1.55	**.93**

Type 2GLS450—Double Sec.

4-8	1⅜ x 3	$1.45	**$0.87**
8-8	1⅜ x 3	1.60	**.96**

300v Surge—250v D.C.W.
Type GLS250—Single Sec.

Cap. Mfds.		Dia.-High	List Price	Net Price
4	1	x 2- 3/16	$0.75	**$0.45**
8	1	x 2-11/16	.95	**.57**
12	1	x 2-11/16	1.15	**.69**
16	1	x 3- 1/4	1.35	**.81**

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